Tutorial problems for "Solar Energy" lecture (23745), WS 2021/2022

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Tutorial Questions #1: Energy processes; Solar energy; Sun temperature and irradiance; Semiconductors; Charge carriers

1. **Energy conversion processes**

   An active person consumes 2,500 kcal of energy in one day.

   A bolt of lightning strikes the ground. It has a voltage of 100 MV and carries a current of 100 kA for 30 µs.

   During a barbeque 1 kg of coal (consisting mostly of carbon) is burned in 1 hour. Assume the following combustion reaction:
   $C + O_2 \rightarrow CO_2 + 4$ eV.

   To make tea an electric heater is used to boil (i.e. heat from 20 °C to 100 °C) 1 kg of water in three minutes.

   The flat roof of a house (6 × 8 m2) absorbs sunlight for a year. Assume the house is in the Netherlands where the annual irradiation is about 1,000 kWh/m2 year.

   A 1.5 V battery with a capacity of 2,300 mAh is charged in 3 hours.

   The whole world population (7 billion people) consuming on average 1,500 watts per person for one year.

   Solar energy Solar energy reaching planet Earth in one hour. Assume a solar constant of 1,361 W/m^2.

   a) For each of the processes above, answer the following questions:
      i. In what form is the energy before and after the process?
      ii. How much energy (in joules) is converted?
      iii. What is the average conversion power (in watts)?

   b) Order the processes from low to high energy.

   c) Order the processes from low to high power.

   Elementary charge: $q = 1.6022 \times 10^{-19}$ C
   Avogadro constant: $N = 6.0022 \times 10^{23}$ mol^{-1} [number of atoms in 12 g of carbon]
   Specific heat of water: c = 4.184 J/g °C
   Radius of Earth: r = 6,378 km
   1 kcal: the amount of energy it takes to heat 1 kg of water by 1 °C.

2. **Solar energy coverage**

   In 2013, the worldwide installed solar power was 140 GW. Assume a capacity factor for solar power of 15%. What percentage of the total electricity generation worldwide was covered by solar energy in 2013?

3. Surface temperature of the sun

The radius of the Sun is 6.96×10^8 m and the distance between the Sun and the Earth is roughly 1.50×10^{11} m. You may assume that the Sun is a perfect sphere and that the irradiance arriving on the Earth is the value for AM0, 1,350 W/m^2.

Calculate the temperature at the surface of the Sun.

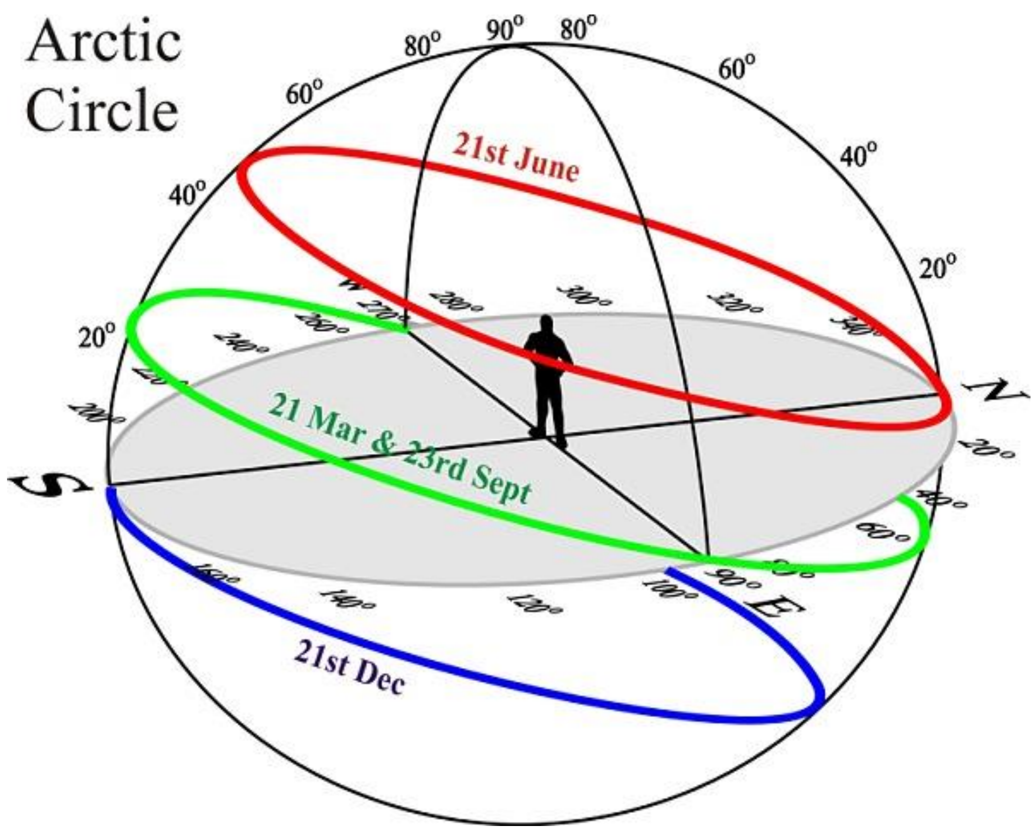
4. Maximum altitude angle

What is the maximum altitude angle of the sun at the Arctic Circle* (lat = 65.8°)?

a) on 21st March?

b) on 21st June?

c) on 21st December?



(= defined as northernmost point where noon sun is just visible on winter solstice and southernmost point at where midnight sun is just visible on summer solstice)*

5. **Light reflection**

Solar light is coming from air ($n_1 = 1$) to the upper glass layer of a solar cell ($n_2 = 1.5$).

a) The light has an angle of incidence of $\theta_i = 0°$. What is the reflectivity at the air–glass interface? Assume that the solar light is randomly polarized.

b) Imagine now an angle of incidence change of $\theta_i = 30°$. Calculate the reflection in this case. Assume again that the solar light is randomly polarized.

6. **Spectral irradiance regions**

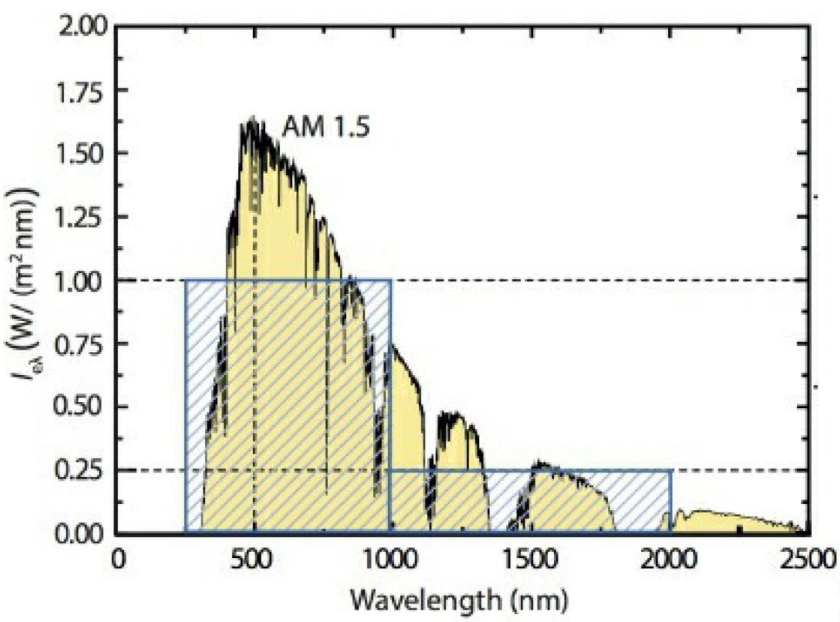
The figure shows the AM1.5 solar spectrum illustrated by the yellow region. A rough approximation of the AM1.5 solar spectrum is represented by the blue region. The spectral irradiance of this region is divided into two spectral ranges,

$I_{e\lambda} = 1.00 \times 10^9$ Wm^{-2} nm^{-1} for 250 nm < λ < 1, 000 nm,

$I_{e\lambda} = 0.25 \times 10^9$ Wm^{-2}m^{-1} for 1, 000 nm < λ < 2, 000 nm.

a) Calculate the irradiance I_e.

b) Calculate the photon flux.



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7. **Multiple choice**

a) Which statement is not true about a semiconductor at room temperature and in the dark?

i. The band gap of the semiconductor is within a range of 0.5 eV to 3 eV.
ii. In a semiconductor only a few electrons fill the conduction band.
iii. In a semiconductor electrons almost fully fill the valence band.
iv. In a semiconductor the valence band is fully filled with electrons.

b) What are the 'free' carriers in the different electronic bands of a semiconductor?

   i. Electrons in conduction band and holes in valence band.
   ii. Holes in conduction band and electrons in valence band.
   iii. Both electrons and holes in conduction band when an electric field is applied.
   iv. Both electrons and holes in valence band when an electric field is applied.

c) What is the maximum number of electrons that can occupy the 3p energy state in an atom?

   i. 2 electrons.
   ii. 6 electrons.
   iii. Only 1 electron can occupy this state according to the Pauli exclusion principle.
   iv. 8 electrons.

d) In case of p-doping of Si, the energy of the acceptor state. . .

   i. . . . is located in the Si bandgap, relatively close to the conduction band.
   ii. . . . is located out of the Si bandgap, relatively close to the conduction band edge.
   iii. . . . is located in the Si bandgap, relatively close to the valence band.
   iv. . . . is located out of the Si bandgap, relatively close to the valence band edge.

e) Considering Si as the bulk material, which of the dopant materials below can be used in order to achieve n doping?

   i. Ge.
   ii. In.
   iii. Ga.
   iv. As.

8. Bandgap

A photon with energy E_{ph} = 1.35 eV is absorbed in a semiconductor creating one electron-hole pair. At the same time, the energy lost due to thermal relaxation of the electron and hole is 0.27 eV. What is the bandgap of the semiconductor?

9. Carrier concentration

Silicon is doped with 10^{16} arsenic atoms per cm^3. Assume intrinsic carrier concentration equal to 1.5×10^{10} cm^{-3} at room temperature. What is the minority carrier concentration at room temperature (T = 300 K)?